Formulations and algorithms for rich routing problems

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Chapter 6

Conclusions and future research

In this thesis we have modeled and solved four different problems combining routing with other decisions. In Chapters 2 and 3 we have considered routing with loading, in Chapter 4 we have examined routing with the location of pickup lockers, and in Chapter 5 we have integrated two time-dependent routing problems, namely the time-dependent vehicle routing problem and the time-dependent shortest path problem. In this section we summarize the content of each chapter and the obtained results, we give insights and propose future research directions.

In Chapter 2, we have introduced, modeled and solved the pickup and delivery traveling salesman problem with handling costs (PDTSPH). We have proven that this problem is a generalization of the pickup and delivery traveling salesman problem (PDTSP) and the pickup and delivery traveling salesman problem with LIFO loading (PDTSPL). We proposed a large neighborhood search heuristic to solve the problem, which we compared against best known solutions on 205 benchmark instances for the PDTSP and the PDTSPL. We provided new best known solutions on 67 instances, besides finding the optimal or best known solution on 125 instances. The heuristic found optimal or near-optimal solutions on a set of small-sized instances for the PDTSPH. We have studied two reloading policies, namely reloading policy 1, where the reloading sequence is the inverse of the unloading sequence, and reloading policy 2, where the reloaded items are positioned in the sequence they will be delivered. Since each rehandling operation has a direct effect on the objective, the reloading policy has a large impact on the objective. Under reloading policy 2, the number of rehandling operations is reduced compared to reloading policy 1, since reloaded items are sorted preventively. We illustrated the trade-off between the travel distance and the number of rehandling operations by diversifying the penalty cost for a rehandling operation. Results show that the number of rehandling operations may be very high when they are not accounted for in the routing model, whereas a large number of these rehandling operations can be eliminated at the expense of a small increase in travel distance, which illustrates the urge to incorporate handling operations in the PDTSP. Since the number of requests for the instances under study is quite high and the capacity of the vehicle is unrestricted, including capacity restrictions is a promising research direction. Another direction for future research is the development of an exact algorithm that is able to solve larger instances of the PDTSPH to optimality. A possibly interesting extension for the PDTSPH is to include multiple stacks.

In Chapter 3, we have introduced the pickup and delivery problem with time windows and handling operations (PDPTWH). We defined two rehandling policies. For both policies, rehandling is only allowed at delivery locations and there is no specific reloading order for the rehandled items. Under the first policy, only compulsory rehandling is allowed. Under the second policy, in addition to compulsory rehandling, preventive rehandling is allowed. For each policy, we proposed a branch-price-and-cut algorithm with an ad hoc dominance criterion for the labeling algorithm used to generate routes. Computational results are reported on benchmark instances for the pickup and delivery problem with time windows. Both algorithms can solve instances with up to 75 requests to optimality within the prespecified time limit of three hours. For the instances under study, increasing the rehandling time leads to an increase in travel costs of up to 24.8%. The travel costs can be reduced up to 3.2% by allowing rehandling policy 2 compared to rehandling policy 1. However, more instances could be solved to optimality by the algorithm under policy 1 and the average computation time is shorter for the algorithm under policy 1 compared to the algorithm under policy 2. In conclusion, even though policy 2 allows more flexibility in the rehandling operations, for the instances under study it does not always results in a larger cost reduction compared with policy 1. This can be explained by the relatively small average number of items in the vehicles for the instances under study. Moreover, a difference in the number of rehandling operations is only observed if the extra time results in a late arrival and thereby an infeasible route. It will be interesting to investigate the effect of the reloading policies for other instances, especially instances with larger vehicle capacities and different time windows. If these instances generate a larger difference between rehandling policies 1 and 2, it might be interesting to consider different rehandling policies, e.g., a rehandling policy that allows rehandling at pickup locations. Another area of future research is the development of heuristics for the PDPTWH in order to investigate larger instances. A natural extension for the PDPTWH is to include multiple stacks. Note, however, that this results in a large increase in the complexity of the model.

In Chapter 4, we have introduced a simultaneous facility location and vehicle routing problem that arises in health care logistics in the Netherlands. We formally defined this problem and solved it by applying a branch-and-bound algorithm to the proposed mathematical formulation. Moreover, we developed a fast hybrid heuristic to solve the problem. Extensive computational results are given on a randomly generated instance set and on an instance set inspired by practice from Alliance Healthcare Netherlands, an industrial partner. The branch-and-bound algorithm was able to solve instances with up to 100 patients and 50 potential lockers to optimality within the prespecified time limit of 2 hours. The hybrid heuristic found optimal or near-optimal solutions for the smaller instances. For the larger instances, the heuristic was able to improve the solutions obtained by the branch-and-bound-algorithm within the time limit of 2 hours, by using only a fraction of the running time. Results indicate that the solutions of the hybrid heuristic are very robust. We have shown that the incorporation of sophisticated methods for opening and closing a locker in our hybrid heuristic has a large impact. Results from the instances under study show that a decrease in the opening cost of the lockers or an increase in the coverage distance results in an increase in the number of opened lockers. It would be interesting for future research to investigate the effect of some of the modeling choices by considering different modeling assumptions. For example, a preference of the logistics company to deliver to lockers over home delivery could be accounted for in the objective by the number of customers that receive home delivery, instead of penalizing the customer routes. Another example is to consider the opening cost and service time of a locker dependent on the number of customers assigned to it. The model in this chapter is a first effort to consider pickup lockers as an option for delivery. Several extensions of this model could be investigated. An option for future research is to offer the option to deliver to a locker nearby other locations, such as the office of a customer or the children's school. Another extension would be to offer the customer a choice for delivery, either at a locker or via home delivery. Different prices need to be associated to home delivery and delivery to a locker, where the price of delivery to a locker can be dependent on the distance between the customer and its closest locker.

In Chapter 5, we have introduced the time-dependent shortest path and vehicle routing problem (TDSPVRP). We provided a mathematical formulation and developed valid inequalities to strengthen the formulation and improve the lower bounds. We created the first set of benchmark instances for the TDSPVRP generated from real traffic data on the road network in Québec City, Canada. We used a simple heuristic to create initial solutions for the problem. We show that the valid inequalities reduce the problem size and ensure that less instances encounter memory issues before starting to solve the problem. Our standard formulation provided very weak lower bounds, the gaps with the best found solutions were between –99.98% and –100.00%. Valid inequalities based on shortest paths imposed to improve the lower bounds turned out to be strong, adding them to the standard formulation resulted in gaps between the lower bounds and the best found solutions between –8.77% and –14.58%. An improvement was made by imposing valid inequalities based on different and more intricate shortest paths, which resulted in gaps between –8.60% and –14.25%. We provided a sensitivity analysis that shows that substantial delays are incurred when traffic is ignored, which supports the importance of including traffic. We provided bounds for all benchmark instances, opening a research avenue for others. We have developed an exact method with the aim of providing and improving dual bounds for the problem. Our lower bounds are expected to be tight. Given the size and difficulty of the problem, heuristics should provide much tighter upper bounds than our exact method. Therefore, state-of-the-art heuristics should be developed in future research. The benchmark instances generated and the lower bounds provided in our research can be used to test the results of those heuristics. The results of these heuristics can also be used to evaluate the impact of path choice. Moreover, more elaborated exact methods should be developed in future research.